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WIRE SUSPENSIONS IN WIND TUNNEL EXPERIMENTS

By Jean Kerneis

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WIRE SUSPENSIONS IN WIND TUNNEL EXPERIMENTS.*

By Jean Kerneis.

For a long time there was accorded, in France, but little credit to the results of wind tunnel experiments. This distrust, though exaggerated, was not entirely unfounded. No accord was possible between the different laboratories, since the polars varied, if not with the time, at least with the balance used. We cannot, however, disavow the services rendered by these early experiments, notwithstanding their inaccuracy. From the comparative viewpoint, even inaccurate experiments may give valuable results, render it possible to clear up a problem and indicate the way to follow, but their comparison requires a perfect knowledge of the experimental conditions and is practically impossible between different laboratories. It is, moreover, very hazardous to make assumptions on the constancy or the mode of variation of an error, when its value and even its causes are not known. The present status of experimental aerodynamics requires, moreover, a closer approximation, while the establishment of a project demands absolute accuracy for a good prevision of the performances. Our laboratories are trying to attain this accuracy. Certainly the coefficient of similitude Vl/μ is far from being reached

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and it seems hardly probable that it ever will be. The size and speed of airplanes are increased much more rapidly than the diameters of wind tunnels or the power of their motors. The effect of this, however, is not so great as has been assumed and its bad repute is due in part to the imputation to it of errors really resulting from totally different causes. These sources of important errors have been gradually eliminated and we may now consider as exact the experimental results obtained in our laboratories.

The elimination of the rigid supports for the models and their replacement by wires constitute a great improvement by rendering negligible the interactions of the support, phenomena of a very complex aerodynamic order which introduce errors often large and always impossible to evaluate. The use of a balance with wires has, however, certain disadvantages. The aerodynamic resistance of the wires is always very large and their use is rather difficult because the whole suspension lacks rigidity and easily becomes distorted. We will here investigate the nature of these distortions, evaluate the errors they entail and describe the methods for taking account of or avoiding them.

Nature of the Distortions

We will briefly explain the principle of the wire balance (Fig. 1). The model is inverted and suspended by two systems of vertical wires a_1 and a_2 to the lift balances B_1 and B_2.

The drag is transmitted by a system of horizontal wires c_3, a restraining wire b_3 at 45° and a vertical wire a_3 attached to the drag balance B_3.

The distortions undergone by this system may destroy the verticality of a_1 and a_2 or the horizontality of c_3. The distortions may be due either to poor initial adjustment or to the stretching of the wires by the aerodynamic stresses.

A. Lack of Verticality of a_1 and a_2

1. Poor adjustment of balance.- We will suppose that as a result of the poor adjustment of the balance, a_1 and a_2 make an angle α with the vertical (Fig. 2), O being at O' and C at C' and a_1, a_2, b_1, b_2 respectively occupying the positions a'_1, a'_2, b'_1 and b'_2.

We will designate by $p\,a'_2$, $p\,b'_2$, etc., the vertical components of the tension of the wires a'_2, b'_2, etc., and by $t\,a'_2$, $t\,b'_2$, etc., the horizontal components of this same tension. If we call ϖ the weight of the model, the following are the equations of equilibrium of the system before the wind

$$\begin{cases} \varpi + pa'_1 + pa'_2 + pb'_1 + pb'_2 = 0. \\ tc'_3 + ta'_1 + ta'_2 + tb'_1 + tb'_2 = 0. \end{cases} \qquad (1)$$

The air current generates the aerodynamic forces P and T which are offset by variations in the tension of a'_1, a'_2 and c'_3. Let us call $p'a'_1$, $p'a'_2$, $t'a'_1$, $t'a'_2$ and $t'c'_3$ the new projections of these tensions.

The equilibrium equations then become

$$\begin{cases} \varpi + P + p'a'_1 + p'a'_2 + pb'_1 + pb'_2 = 0. \\ T + t'c'_3 + t'a'_1 + t'a'_2 + tb'_1 + tb'_2 = 0. \end{cases} \tag{2}$$

From equations (1) and (2) we deduce

$$\begin{cases} P + (p'a'_1 - pa'_1) - (pa''_2 - pa'_2) = 0. \\ T + (t'c'_3 - tc'_3) + (t'o'_1 - to'_1) + (t'o'_2 - to'_2) = 0. \end{cases}$$

In the first equation $(p'a'_1 - pa'_1)$ and $(p'a'_2 - pa'_2)$ are the stresses measured on the balances B_1 and B_2. Their sum is therefore equal to the lift.

In the second equation $(t'c'_3 - tc'_3)$, the stress is measured on the balance B_3. This stress is therefore equal to the drag, to within the error $(t'a'_1 - ta'_1) + (t'a'_2 - ta'_2)$.

We now have

$$\frac{t'a'_1 - ta'_1}{p'a'_1 - pa'_1} = \tan\alpha = \frac{t'a'_2 - ta'_2}{p'a'_2 - pa'_2}$$

whence the error =

$$(t'a'_1 - ta'_1) + (t'a'_2 - ta'_2) = \tan\alpha\,[(p'a'_1 - pa'_1) + (p'a'_2 - pa'_2)] = P\tan\alpha.$$

Order of magnitude of the error.- The error in the drag is therefore proportional to the lift, i.e., it varies with the angle of attack. It depends also on the distance between the model and the lift balances and is evidently of the magnitude of OO', i.e., of the error of adjustment.

Let us assume that $\alpha = 0.1$ degree and that $\tan\alpha = 0.0017$. On the other hand, the lift of a wing may reach 15-20 times the drag and the error then becomes 0.0017 x 20 T, i.e., error/T = relative error = 0.034 or 3.4%, a far from negligible error, notwithstanding the smallness of α. If the adjustment is not carefully made, the error may be quite large.

2. Imperfect initial adjustment. Effect of elongation of wire.- Due to the action of the aerodynamic forces on the model, the group a_3, b_3, c_3 is distorted by the stretching of each of its components. The result is a shifting of O and C, toward the rear, to the positions O' and C' (Fig. 3). Thus an error is produced, which we are going to evaluate. We will use the same notation as in the preceding cases.

At the beginning, the equilibrium is defined by

$$\begin{cases} \varpi + pa_1 + pa_2 + pb_1 + pb_2 = 0. \\ tc_3 + tb_1 = 0. \end{cases} \qquad (1)$$

In the wind, these become

$$\begin{cases} \overline{\varpi} + P + pa'_1 + pa'_2 + pb'_1 + pb'_2 = 0. \\ T + ta'_1 + ta'_2 + tc'_3 + t'b_1 = 0. \end{cases} \qquad (2)$$

Whence we deduce

$$\begin{cases} P + (pa'_1 - pa_1) + (pa'_2 - pa_2) = 0. \\ T + (tc'_3 - tc_3) + (ta'_1 + ta'_2) = 0. \end{cases} \qquad (3)$$

As before, the first of these equations indicates that the lift is accurately measured on the balances B_1 and B_2; the second, that the drag is accurately measured on the balance B_3 to within the error $t\ a'_1 + t\ a'_2 = \tan\alpha\ (p\ a'_1 + p\ a'_2)$. We can therefore write

$$p\ a'_1 + p\ a'_2 = (p\ a'_1 - p\ a_1) + (p\ a'_2 - p\ a_2) + p\ a_1 + p\ a_2$$

and we have the error $= \tan\alpha\,(P + p\ a_1 + p\ a_2)$. In this case, the value of the counterpoise and the weight of the model are added to the lift.

We can assume that OO' is proportional to the drag and write $\tan\alpha = KT$ (K having here the inverse magnitude of a force). We then have the error $= KT\ (P + p\ a_1 + p\ a_2)$, i.e., error/T = relative error $= K\ (P + p\ a_1 + p\ a_2)$. The recoil OO' is not large, but it is often quite important, due to the elastic distortion. This error may attain 5% for great lifts.

These two causes of error may occur simultaneously and it is obvious that the impossibility of evaluating the distortions with precision prevents the calculation of the errors they introduce. It may be possible to avoid these distortions, either by improving the adjusting mechanism of the balance or by diminishing the stress on the system of drag wires or by inventing special indeformable combinations. The first method is hardly compatible with the size of the wind tunnels, the difficulty of establishing precise and practical adjusting devices, light and little resistant to the wind, and especially with the flexibility of experimentation required in the laboratories. As to increasing the size of the wire, this is hard to reconcile with the necessity of reducing to the minimum the already considerable drag of the suspension wires.

However this may be, the whole mechanism must be studied with the object of reducing the distortions as much as possible. We call especial attention to the matter of the dynamometers. It is practically impossible to eliminate their employment, which necessarily entails quite important errors.

B. Lack of Horizontality of C_3

This lack may be due to a poor adjustment of the balance or to an elastic distortion consisting of a vertical displacement of O under the action of the lift (Fig. 4).

On proceeding as before, by double projection, we find an error in the lift amounting to $T \tan\beta$, for faulty adjustment, and $(T + t\ b_1) \tan\beta = K'\ P\ (T + t\ b_1)$ for elastic distortion, with the possibility of a combination of these two errors. This error, which is negligible in the ordinary case of airfoils, may be of some importance when the drag is large with relation to the lift, which then becomes difficult to measure.

The double projection of a_3, b_3 and c_3 likewise reveals an error in drag equal to $T \tan\beta$ for faulty adjustment and $(T + t\ b_1) \tan\beta$ for elastic distortion. This error, which is generally negligible, depends, however, on $\tan\beta$, whose value it is well to limit by diminishing OO' or by increasing OA. It is very important, however, to give sufficient length to OA, which one is tempted to reduce in order to diminish the horizontal recoil OO'. We may even experiment with different lengths of OA, according to whether we wish to measure the lift or the drag.

How to Eliminate these Errors

a) Static calibration.- As already mentioned, it does not seem possible to avoid deformations of the balances. We can doubtless reduce them considerably and this precaution must be taken when a balance is being designed. The value of the results depends, however, on the precision of a difficult adjustment. It seems necessary, therefore, to proceed afterwards to an integral static calibration, that is to say, by reconstituting, with weights placed at O and C, the equilibrium with the weights measured at B_1 and B_2. Only then can we proceed to a calibration of the drag. These operations are long and difficult. The adoption of these supplementary measures further diminishes the approximation of the test, but they constitute an indispensable guaranty, which completely satisfies the mind.

b) Special balances.- It is of interest to consider here the somewhat special case of the balance used at the Aerotechnic Institute of Saint Cyr. After being transformed, by various stages and for different reasons, it now constitutes a balance which partially eliminates the errors due to distortions. This result, obtained in an entirely fortuitous manner, may lead to new and interesting solutions.

Fig. 5 is a diagram of this aerodynamic balance, as used with rigid supports. It has two parallelograms, A B C D of drag and F G H I of lift. The measurements are made at M and N. T equals the measurement at N and P equals the measurement at N plus the measurement at M. This balance is too well known for us to dwell on its operation and advantages, especially from the viewpoint of sensitivity.

After the elimination of rigid supports and their replacement by wires, it has been arranged as shown in Fig. 6. The model is supported by counterpoises at the top. The lift is measured at M and the drag at N. We will consider the effect of the above-mentioned distortions on this balance.

A. Lack of Verticality

<u>1. Poor adjustment of the balance (Fig. 7)</u>.- We will assume that, due to poor adjustment of the balance, a_1 and a_2 make an angle α with the vertical. O is at O' and C at C' and a_1, a_2, b_1 and b_2 respectively occupy the positions a'_1, a'_2, b'_1 and b'_2. We will designate the forces the same as before. The forces measured by the two lift and drag balances will be designated by P_m and T_m.

As above, we have, for the model, the following equations of equilibrium:

Before the wind

$$\begin{cases} \overline{\omega} + p\,a'_1 + p\,a'_2 + p\,b'_1 + p\,b'_2 = 0 \\ t\,c'_3 + t\,a'_1 + t\,a'_2 + t\,b'_1 + t\,b'_2 = 0 \end{cases} \qquad (1)$$

In the wind:

$$\begin{cases} \overline{\omega} + P + p'a'_1 + p'a'_2 + p\,b'_1 + p\,b'_2 = 0 \\ T + t'c'_3 + t'a'_1 + t'a'_2 + t\,b'_1 + t\,b'_2 = 0 \end{cases} \qquad (2)$$

By subtraction:

$$\begin{cases} P + (p'a'_1 - p\,a'_1) + (p'a'_2 - p\,a'_2) = 0 \\ T + (t'c'_3 - t\,c'_3) + (t'a'_1 - t\,a'_1) + (t'a'_2 - t\,a'_2) = 0 \end{cases} \qquad (3)$$

On the other hand, the equilibrium equations of the balance, before and during the wind, give, by subtraction, the following equations (on replacing a'_3 by c'_3 due to the wire being at an angle of 45°):

$$\begin{cases} (p'a'_1 - p\,a'_1) + (p'a'_2 - p\,a'_2) + (t'c'_3 - t\,c'_3) + T_m + P_m = 0 \\ (t'a'_1 - t\,a'_1) + (t'a'_2 - t\,a'_2) + (t'c'_3 - t\,c'_3) + T_m = 0 \end{cases} \qquad (4)$$

From equations (3) and (4) we obtain:

$$\begin{cases} 1) \quad T_m = T \\ 2) \quad P = P_m + (t'c'_3 - t\,c'_3) + T_m \end{cases}$$

or

$$P = P_m - (t'a'_1 - t\,a'_1) + (t'a'_2 - t\,a'_2)$$

The drag measurement is therefore exact.

For the lift, the error is $(t'a'_1 - t\,a'_1) + (t'a'_2 - t\,a'_2)$ a value which we have seen to be equal to $P\tan\alpha$, or a relative error of $\tan\alpha$. This error can never amount to 1% and is negligible in all cases.

<u>2) Perfect initial adjustment.</u> <u>Effect of elongation of the wires.</u>- Proceeding as above, we obtain, for the model, the following equations:

$$\begin{cases} P + (p\,a'_1 - p\,a_1) + (p\,a'_2 - p\,a_2) = 0 \\ T + (t\,c'_3 - t\,c_3) + t\,a'_1 + t\,a'_2 + t\,b'_2 + (t\,b'_1 - t\,b_1) = 0 \end{cases}$$

and for the balance:

$$\begin{cases} (p\,a'_1 - p\,a_1) + p\,a'_2 - p\,a_2 + t\,c'_3 - t\,c_3 + T_m + P_m = 0 \\ t\,a'_1 + t\,a'_2 + t\,c'_3 - t\,c_3 + T_m = 0 \end{cases}$$

On combining these equations as above, we obtain, for the drag, an error equal to

$$t\,b'_2 + (t\,b'_1 - t\,b_1).$$

This error depends entirely on the tension of b_1 and b_2, i.e., on the value of the upper counterpoises, which are constant not only during the same test, but during a whole series of tests. If b_1 were vertical, we would have, as error, $(p\,b_1 + p\,b_2)\tan\alpha$ and, on assuming $\tan\alpha = KT$, the relative error becomes $(p\,b_1 + p\,b_2)\,K$, which is the relative error of the independent and therefore constant lift.

For the lift, the equation $P = P_m + T_m + (t\ c'_3 - t\ c_3)$ indicates an error equal to

$$(t\ a'_1 + t\ a'_2)$$

or
$$(P + \overline{\varpi} + p\ b_1 + p\ b_2)\ \tan\alpha$$

The relative error is:

$$\tan\alpha + \frac{\varpi + Pb_1 + Pb_2}{P}\ \tan\alpha$$

$\tan\alpha$ always being very small.

The absolute error $(\varpi + Pb_1 + Pb_2)\ \tan\alpha$ is, in normal cases, of the order of the sensitivity of the lift balance. In certain special cases, in testing hulls, for example, it is important to take it into account.

B. Lack of Horizontality of C_3

The equations of equilibrium show that the errors in the drag and in the lift are the same as with the old balance and that the same precautions must be taken. In this case, however, the length of c_3 is clearly defined by that of $CR = BC$ and it is no longer possible to operate with different lengths, according to the cases. This consideration must affect the choice of the dimensions of the drag parallelogram.

C. Advantages and Disadvantages of this Balance

The drag errors are independent of the lift. They are therefore determined very simply and rapidly by a static calibration, which can be made for several values of the drag.

The lift errors, which are negligible in the ordinary cases of airfoils, are no longer so in the case of tests where the lift is small in comparison with the counterpoises and drag.

The disposition of the balance, from the very fact of its principle, renders impossible the integral calibration referred to above. We must bear in mind that this calibration is of value only in so far as it does not risk the introduction of new errors which might exceed or simply equal the errors it is desired to eliminate. A very thorough investigation of this matter should be made and we should endeavor to find some simple device which would be easy to adjust and control.

Conclusions

The problem is too complex for us to be able to say which is the better solution: the balance of the Saint Cyr type, which is very practical in certain cases but not in other cases, or the old method of suspension with its indispensable calibration. We have here simply tried to show the great importance which the errors inherent in wire suspensions may assume.

Of course the value of a balance depends on the possibility and the facility of eliminating the errors, but this is not the only consideration. All the questions of pendularity, sensitivity and inertia have their importance, but they are too well known for it to be worth while for us to discuss them.

Reasons of a practical nature, the location of the laboratory, efficiency of the personnel, total efficiency, cost, etc., contribute their part to the choice of a balance. Reasons of a physiological or even of a psychological order may, according to the nature of the personnel, lead to different solutions.

Under all circumstances, however, accuracy is the primordial and necessary characteristic for which we must strive. This treatise indicates under what conditions it may be obtained.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

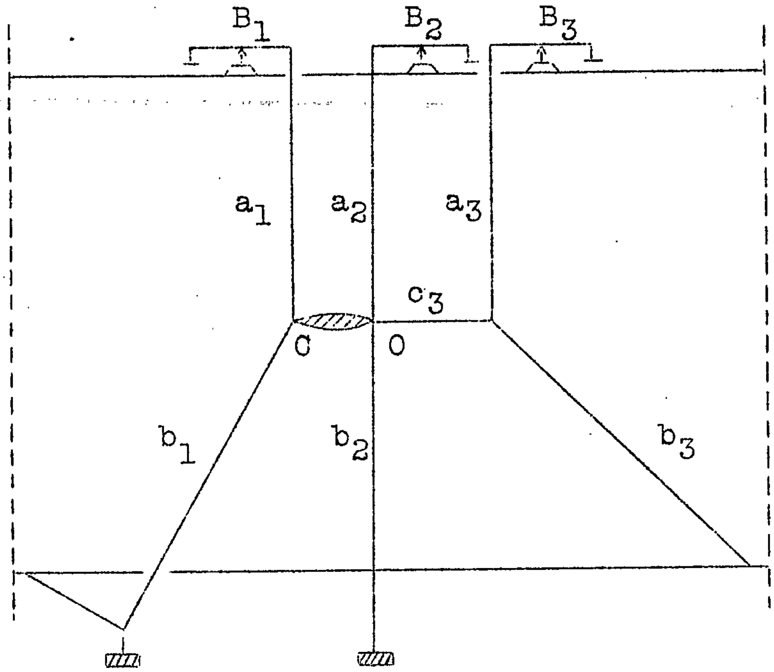

Fig.1

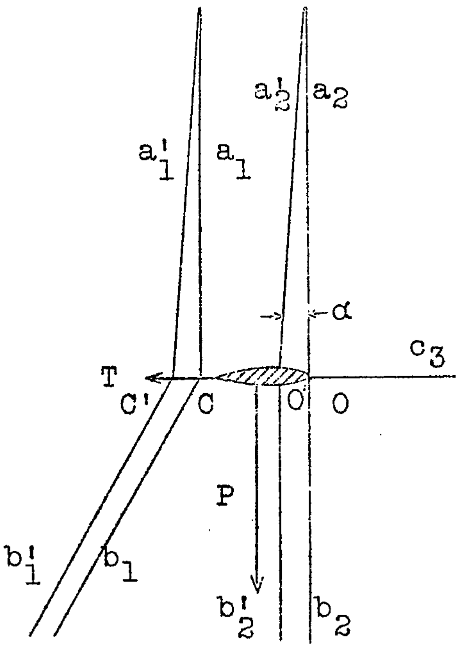

Fig.2

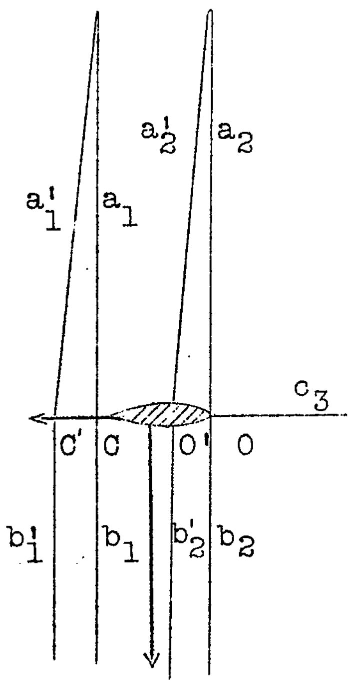

Fig.3

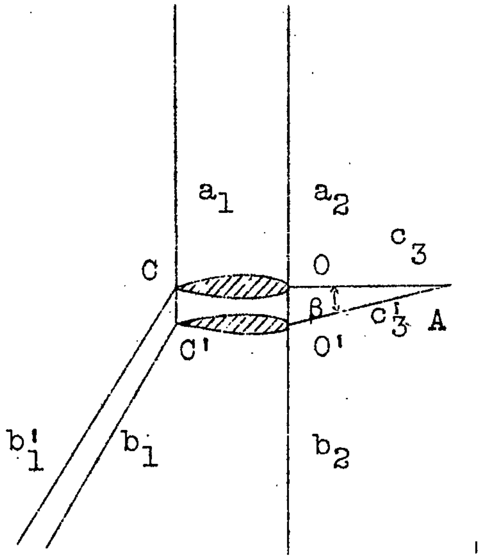

Fig.4

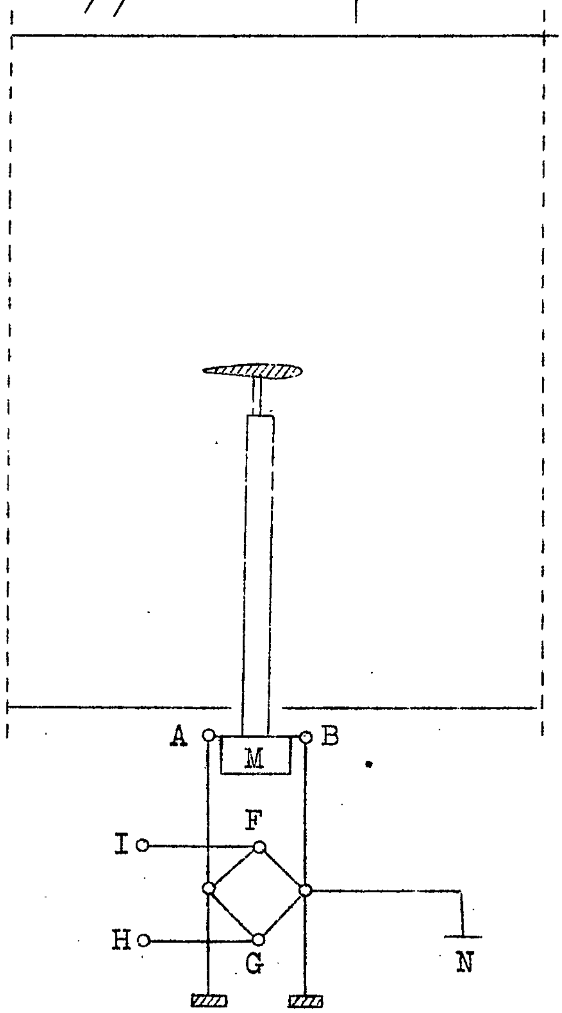

Fig.5

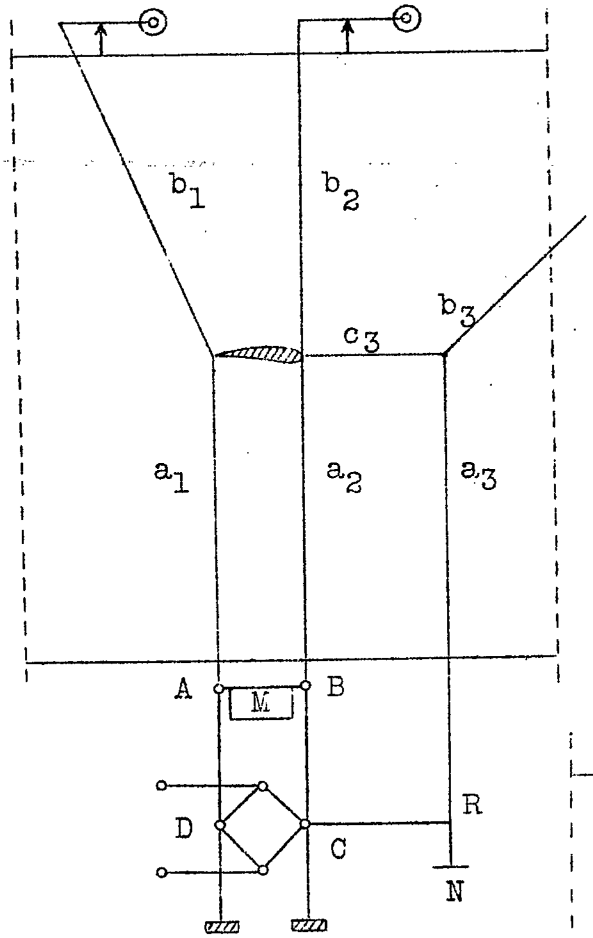

Fig.6

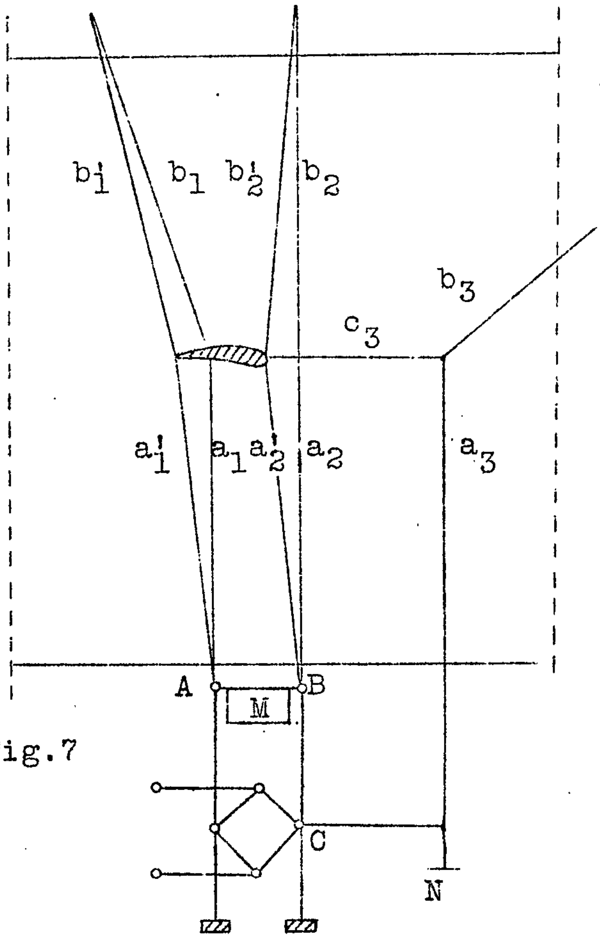

Fig.7